# Biosolids and Plants

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Over the years one of the primary concerns with the safety of land application of biosolids has been how the biosolids will affect plants grown on biosolids amended soils. These concerns are about both the health of the plant and the health of anyone or anything that eats the plant. Although these concerns have sometimes focused on the great (or perceived to be great) unknowns in biosolids, in reality, there are three main areas to consider when you want to understand what can happen to plants that are grown in biosolids amended soils. These areas are disease causing organisms, metals of concern, and organic chemicals of concern. Each will be discussed below, and the basis for any concern will be evaluated.

The first thing to realize is that plants are the primary reason biosolids are applied to land. In addition to nitrogen, biosolids contain just about all of the nutrients that plants need to grow. Plants get the minerals that they require from the soil. They need some elements in large quantities. These are referred to as macronutrients. There are additional elements that plants require in small quantities. These are referred to as micronutrients. The most common types of synthetic fertilizers contain nitrogen, phosphorus, and potassium or N, P, and K. These are the most important and most commonly deficient nutrients for plant growth. However, other elements can also be deficient for plant growth. Using a fertilizer with macro- and micronutrients, like biosolids or manures, will generally provide the full suite of nutrients that plants require. (The one exception is potassium. Although biosolids contain potassium, it is not always present in high enough quantities to meet crop demand when biosolids are applied to meet the nitrogen needs of the crop.) This explains why biosolids are good for plants. The next task is to address concerns regarding their safety.

**Necessary Plant nutrients**

| **Macronutrients** | | | **Micronutrients** | | |
|---|---|---|---|---|---|
| | Concentration g kg | In Biosolids? | | Concentration mg kg | In Biosolids? |
| Nitrogen | 10-50 | √ | Boron | 6-60 | √ |
| Phosphorus | 1-4 | √ | Copper | 5-20 | √ |
| Potassium | 10-40 | √ | Iron | 50-250 | √ |
| Calcium | 2-10 | √ | Chloride | 2-2000 | √ |
| Magnesium | 1-4 | √ | Manganese | 20-500 | √ |

| | | | | | |
|---|---|---|---|---|---|
| Sulfur | 1-4 | √ | Molybdenum | 0.2-1 | √ |
| | | | Zinc | 25-150 | √ |

***Disease causing organisms***

When water enters a wastewater treatment facility, it contains a variety of organisms that can cause disease in people; these are called "pathogens." In addition to removing excess nutrients, one of the primary tasks of the facility is to clean the water to remove enough of these organisms so that the potential for people to get sick from being exposed to the treated water is minimal. Water from treatment plants is generally released to a natural water body. For example, cleaned water (or "effluent") from the wastewater treatment plants in King County is released into Puget Sound. In Washington, DC, water from the Blue Plains treatment plant is released into the Anacostia River. Likewise, before biosolids produced by treatment facilities can be applied to land, they must meet standards for pathogen reduction.

E. coli bacteria are often the cause of illness when untreated animal manures are used as fertilizers

Class B biosolids have been treated to kill the vast majority, but not all, of the pathogens. If you eat a vegetable or fruit that has come in direct contact with Class B biosolids, there is the potential to eat enough of a disease -causing organism to get sick. Land application of untreated human wastes was banned for this reason. The use of night soil, the term used to describe human waste that was used for fertilizer, was known to occasionally make people ill. As part of the regulations on biosolids use, any biosolid that has been treated to meet Class B pathogen requirements is not allowed to be used to fertilize a crop for direct human consumption. If a crop can be eaten raw, Class B biosolids can not be used to fertilize the crop. No Class B biosolids are allowed near strawberries or tomatoes. In addition, there is a lengthy waiting period after the last application of Class B biosolids and the time garden vegetable crops can be grown. The time period is based on the die-off time for different pathogens in the soil. These organisms are comfortable in the human intestinal tract. The conditions in the soil or on a plant leaf is much more hostile, and so the agricultural field or forest can serve to further treat biosolids for complete pathogen reduction. Die-off times for different organisms are listed below (Gerba and Smith, 2005).

| | **Soil** | | **Plant** | |
|---|---|---|---|---|
| **Pathogen** | Absolute Max | Common Max | Absolute Max | Common Max |
| Bacteria | 1 yr | 2 mo | 6 mo | 1 mo |
| Viruses | 6 mo | 3 mo | 2 mo | 1 mo |
| Protozoa | 10 d | 2 d | 5 d | 2 d |
| Helminths | 7 yr | 2 yr | 5 mo | 1 mo |

For some crops, like field corn, soybeans, and wheat, where there is little or no potential for direct contact between the biosolids and the edible portions of the crop, use of Class B biosolids is encouraged by US EPA and is common.

In addition to pathogen reduction or elimination requirements, the EPA biosolids regulations also require biosolids to be treated to reduce vector attraction. Vectors are anything that could potentially carry a pathogen from a biosolids application site to a population center. In this case, a population center means a place where people live, not just a large metropolitan area. Vectors are normally things like flies or rats that can be attracted by the smell of the biosolids and would potentially find the notion of eating or rolling in the biosolids a good one. To reduce vector attraction, the biosolids have to be treated to reduce biodegradable organics. This can be done biologically or chemically, as well as through drying. Vector attraction reduction regulations apply to Class A and B biosolids.

These regulations appear to be working. Although there have been numerous documented instances where animal manures have made people sick as a result of their being used to fertilize garden crops, there have been no documented instances of biosolids causing any illnesses (Smith and Perdek, 2003).

***Metals in Biosolids***

As was discussed at the beginning of this section, biosolids contain the wide range of elements that plants need to grow. In addition, biosolids also contain elements (e.g. “heavy metals”) that are not required for plant growth and that can also be hazardous to the environment. The scientists that evaluated and conducted the research that formed the basis for the EPA regulations on biosolids focused their efforts on understanding the behavior of metals in biosolids. Although direct ingestion of biosolids by different animals (goats and cows were two examples) were studied, the bulk of the research that was done focused on plant uptake of metals and the potential for animals or people who ate those plants to become ill. In fact, aside from regulations on pathogen content, metals are the only category of contaminants that are regulated for biosolids.

In order to understand the conclusions that the scientists reached for metal limits in biosolids, it is helpful to understand that not all of the different metals of concern behave the same way in soils or will be taken up by plants. Lead, for example, is one metal that can be toxic to people and wildlife if it is ingested in large quantities. Lead in biosolids, however, is not a concern for plant uptake because it is very insoluble in soils and, therefore, cannot be easily absorbed by plants. Even in highly lead contaminated soils, plant lead concentrations are almost always very low. Other elements, like arsenic and chromium, are also not a concern for plants and crops, because plant uptake of both of these elements is also minimal. Plants don't need them to grow, and they are generally insoluble in soils.

There are other elements, including zinc and copper, that plants do need to grow. Even though both of these elements are necessary for plant growth, if plants get too much of them, they can be harmful. In high enough concentrations, they can even kill plants. Both zinc and copper are also necessary for people. But we are better equipped at dealing with excess zinc and copper than plants: if we ingest excess amounts, we just excrete the excess, the same as the body does with excess iron.

Cadmium is one element that can harm people and animals through ingestion of plants that contain high cadmium concentrations. In fact, in Japan after World War II, people living downstream from a smelter ate rice that had high concentrations of cadmium. Because their diets were deficient in necessary nutrients, a high proportion of the cadmium that they ate was absorbed in their intestines. As a result of the combination of malnutrition and high cadmium, many people developed *itai itai* disease, resulting in multiple bone fractures. There were also some deaths attributed to excess cadmium in diets. In addition, wildlife in the vicinities of smelters have shown that liver and kidney function can be compromised when animals eat too much cadmium. A recent study observed that birds that ate willow buds grown on mine-tailing impacted soils had reproductive problems because of the excess cadmium in their diets.

Because of known instances of fatalities due to elevated cadmium in plant tissue, scientists focused on this element when conducting research on the potential for metals in biosolids to cause harm to the environment. Like lead and chromium, cadmium is not necessary for plant growth. One thing that makes cadmium different from those other elements is that it is relatively soluble in soils. In addition, it is closely related to zinc, which is a necessary plant nutrient. Plants can take up cadmium in cases where there is insufficient zinc.

In order to determine how much cadmium could be in biosolids without causing harm to the environment, the scientists set out to determine how much cadmium would end up in plants when biosolids were applied to soils. They looked at a wide range of plants, biosolids, and soils. Different plants take up different amounts of cadmium when grown in the same soil. Although you may have been told to eat your greens as a kid and may relish your salads as an adult, lettuce and Swiss chard take up more cadmium than all other garden vegetables. Wheat and potatoes take up much less. Interestingly, plants grown where cadmium was added as a *chemical salt* will have much higher cadmium concentrations than iplants grown where biosolids were the source of cadmium. In addition, the scientists found that a small application of biosolids with high cadmium concentrations, will cause higher plant cadmium concentrations than a large application of biosolids with low cadmium concentrations. Soils with higher salt concentration will have higher plant cadmium than soils with low salt concentrations. Finally, they also found that sandy acidic soils will generally have plants with higher cadmium than fine textured basic soils.

Taking all available data from all types of plants, biosolids, and soils, the scientists came up with plant uptake equations, so that they could calculate how much cadmium would be in the edible parts of plants when biosolids with different cadmium concentrations were added to the soil. They then used a USDA model of what people eat, along with the accepted value of the amount of cadmium we can ingest without doing any harm, to figure out how much cadmium could be in biosolids without causing a health risk. Their protective number for the amount of cadmium allowed in biosolids is based on someone eating over 60% of their food (including meat) from home gardens with soil that consists solely of biosolids for over 50 years. The number that the scientists came up with was 21 parts per million of cadmium in biosolids. The number that EPA actually decided to use in the regulations is 39. (There is still some controversy about EPA's decision, but the conservative assumptions made by the scientists provide ample protection, even with EPA's number.)

As the dangers associated with cadmium have become understood, the use of this metal has decreased. The amount of cadmium, as well as other metals and organic chemicals, that industries are allowed to release into municipal wastewater treatment systems is now regulated and greatly reduced. As a result of these factors, there just isn't much cadmium in biosolids. Average cadmium concentrations in biosolids in the state of New Jersey, for example, have decreased from 9.4 ppm in 1982 to 3.5 ppm in 1997. Trends in New Jersey are similar to those in treatment plants across the country, and the trends for cadmium are mirrored for all other metals in biosolids. So for the metal in biosolids that has the highest potential to cause harm to people, concentrations in biosolids are a fraction of the regulatory limits. And the limits themselves are based on conservative assumptions. In fact, biosolids are currently being used on metal contaminated sites as a way to *reduce* the availability of metals at those sites and restore plant growth. When biosolids and lime are added to these former mining sites, plant concentrations of cadmium and other metals go from near toxic levels to normal ranges. This allows these landscapes to recover from being barren and devoid of plant growth to luxurious plant cover.

It can be helpful to consider how an application of biosolids can change total soil metals. If you take average biosolids from New Jersey and apply them to agricultural land to supply the nitrogen needs of a crop for 20 years, you will be applying 5 tons per acre x 20 years - or 100 tons per acre of biosolids. The biosolids will have 3.5 ppm cadmium. We can say that the soil has 0 ppm cadmium (although, in fact, all soils have traces of cadmium naturally) and that the top 6 inches of soil weigh 1000 tons. Twenty years of biosolids applications would raise the total soil cadmium concentration to just 0.35 ppm – about 100 times lower than the EPA standard for biosolids. If the biosolids were applied to forest land as they often are in the Pacific Northwest, the changes in total cadmium would be different. In forestry, generally about 4 biosolids applications are made from the time trees are planted until they are harvested 40 years later. That would mean that soil cadmium would increase much more slowly than it would in conventional agriculture. In forty years, total soil cadmium in a forest would have increased to 0.07 ppm.

By carefully studying how potentially toxic elements, such as cadmium, behave in biosolids, soils, and plants, scientists and regulators have devised standards that allow the maximum benefits of using biosolids to fertilize plants while ensuring the safety of plants, crops, animals, and people.

***Organic chemicals in plants***

Biosolids can contain trace concentrations of potentially hazardous organic chemical compounds. When the regulations for biosolids were being developed, the scientists considered including a range of toxic organic chemicals in the regulations. However, concentrations of these chemicals in biosolids (based on a national sewage sludge survey) were all significantly below what would have been set as the regulatory limits. This was true when the Part 503 regulations were written, and was also true recently when the potential to regulate dioxin concentrations was considered. In addition, use of many of the most toxic compounds had been banned. With decreased use, the potential for concentrations in biosolids to increase was minimal.

One of the important things to realize about organic chemicals in biosolids is that, as a rule, plants don't take up organic compounds. They are able to fix their own carbon through photosynthesis. Unlike us, they don't need to eat carbon-rich compounds to survive. They get mineral nutrients from soil solutions, but carbon compounds enter into plant roots only by accident. In order for organic chemicals to even have a chance of getting into the plant roots, they first have to be in soil solution and then be small enough to get into the root through ion channels. The only other way that they can get into plant roots is by going through the lipid cell layer. To do that, they would need to be insoluble in water, making direct contact between the root and the compound the method of gaining entry. Once in the plant, the chemical would need to be moved, in large enough quantities, from the roots to the edible part of the plant for it to cause harm to people or animals eating the plant.

Because concentrations of dangerous organic chemicals in biosolids are so low, and the potential for them to be taken up by plants is so small, the risk to plants or consumers of plants associated with this category of contaminants is minimal.

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